Report to Congress

Roadmap for the Hypersonics Programs of the Department of Defense

National Defense Authorization Act
for Fiscal Year 2007
Pub. L. No. 109-364

Joint Technology Office on Hypersonics
Director, Defense Research & Engineering

February 2008

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Roadmap for the Hypersonics Programs of the Department of Defense

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PREFACE

The John Warner National Defense Authorization Act for Fiscal Year 2007 Pub. L. No. 109-364 directs the Secretary of Defense to establish within the Office of the Secretary of Defense a Joint Technology Office on Hypersonics (JTOH). Major functions of the JTOH specified in the NDAA language include the following:

- Coordinate and integrate current and future research, development, test, and evaluation programs and system demonstration programs of the Department of Defense on hypersonics
- Develop, and every two years revise, a roadmap for the hypersonics programs of the Department of Defense
- Approve demonstration programs on hypersonic systems
- [Coordination] with the programs on hypersonics of the National Aeronautics and Space Administration
- Conduct on an annual basis a review of …the funding available for research, development, test, and evaluation and demonstration programs within the Department of Defense for hypersonics … to determine whether or not such funding is consistent with the roadmap developed

The Report contains the FY2008 Roadmap for the Hypersonics Programs of the Department of Defense and leveraged programs of the National Aeronautics & Space Administration's Aeronautics Research Mission Directorate. The Roadmap herein was developed by Office of the Undersecretary of Defense for Science and Technology with representatives from the DoD Military Departments/Defense Agencies and NASA.

APPROVED BY:

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John J. Young, Jr.
Under Secretary of Defense
(Acquisition, Technology, & Logistics)

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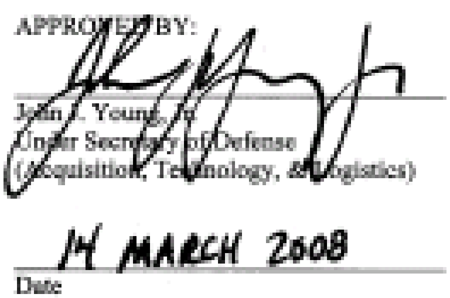
Date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14 MARCH 2008
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Introduction

Hypersonic flight has the potential to support transformation in the DoD by providing advanced capabilities to the warfighter for disrupting enemy operations and protecting U.S. assets and troops. Missiles or aircraft traveling at hypersonic speeds may offer the capability to strike time-critical targets at long distances, delivering a quick and decisive response with potentially reduced logistics footprint. Hypersonic weapons may possess the energy to defeat some hardened and deeply buried targets while minimizing collateral damage, a scenario which has become increasingly important in recent and on-going conflicts. Maneuverable hypersonic interceptors could reach and defeat a broad range of potential threats before they impact U.S. interests. Finally, hypersonic flight holds the promise of assured, on-demand access to space through the development of reusable highly responsive launch vehicles. These vehicles could be used to place new assets into orbit or to enhance the capability and survivability of existing space systems. In short, hypersonic flight technologies may lead to transformational capabilities for prompt global strike and assured, on-demand access to space.

As a result of the benefits to be realized from hypersonic flight, DoD investments have been made in hypersonics science and technology (S&T) to develop technologies leading to transformational capabilities such as prompt global strike and assured access to space. This effort has been supported by all three Military Departments and the Defense Advanced Research Projects Agency (DARPA), leading to an integrated, DoD-wide hypersonics technology development effort. In addition, the DoD collaborates and leverages hypersonics research with the National Aeronautics and Space Administration (NASA) Aeronautics Research Mission Directorate and Exploration Systems Mission Directorate.

The DoD investment strategy for hypersonic technology development employs a "stepping stone" approach that advances and incrementally tests key technologies which then form the basis for the next step, potentially leading to weapons and platforms such as prompt global strike and reusable launch vehicles for responsive space access. This approach helps to mitigate the risks inherent in any truly transformational technology advancement by allowing the continuous incorporation of valuable lessons learned into the next technology development phase. Moreover, this approach provides for early transition of technologies into integrated systems as they become available. In this way, potential benefits from hypersonic technologies may be realized by operational users much sooner. A strong S&T base is also maintained that continues to advance the state-of-the-art in hypersonic technology.

The Joint Technology Office on Hypersonics (JTOH) has been formed to coordinate and integrate hypersonics RDT&E being executed by the DoD Military Components and Defense Agencies. The JTOH has developed a set of technology and technology transition roadmaps which detail the DoD hypersonic RDT&E activities and provide a potential path to future acquisition opportunities. These roadmaps provide an integrated view of DoD hypersonic RDT&E and leveraged hypersonics research investments of the NASA Aeronautics Research Mission Directorate. This report contains these roadmaps along with a brief description of the organizational structure of the JTOH.

DoD Hypersonic RDT&E

The Department's hypersonics RDT&E program should ensure that warfighters of today and tomorrow have superior and affordable technology options to meet their missions, and to give them unmatched capability to defeat any adversary on any battlefield. Accordingly, the mission of hypersonic RDT&E of the Department is to explore, develop and mature hypersonic technologies such that they provide viable technology options for future warfighter systems meeting those goals. Hypersonic technologies, when sufficiently matured, can be transitioned to acquisition programs or provide technology candidates for Analysis of Alternatives (AOA) for mission areas such as long-range strike, prompt global strike, and operationally responsive space. While specific hypersonic mission requirements have not yet been formalized by the Department, the impact on future capability from hypersonic technology could be significant and the Department's hypersonic RDT&E programs are planned and executed to provide options for future warfighters.

Joint Technology Office on Hypersonics

Purpose

The Joint Technology Office on Hypersonics (JTOH) has been formed in accordance with the John Warner National Defense Authorization Act for Fiscal Year 2007 Pub. L. No. 109-364, section 218. The purpose of the JTOH is to integrate DoD hypersonic RDT&E activities across the Military Departments and Defense Agencies, and to coordinate with other government agencies (e.g., NASA). The JTOH provides linkage to the warfighter by communicating potential capabilities the current hypersonic RDT&E investment will enable and facilitating a better understanding of warfighter technology needs to the RDT&E community. The JTOH will establish and maintain links to the operational and intelligence communities to understand emerging threats and needs that may be addressed by hypersonics technologies. Finally, the JTOH will serve as the primary point-of-contact for the Department on hypersonics RDT&E including providing advice to DoD senior leadership and interfacing with the executive and legislative branches and industry.

Scope

The hypersonics domain can encompass an expansive span of technologies ranging from mature operational systems such as rocket-propelled ballistic missiles to far-reaching future systems such as single-stage-to-orbit vehicles. However, to best achieve the maximum potential of the JTOH and utilize its available resources, the technology scope of the JTOH is defined to be,

Hypersonics Technologies that Enable

Maneuvering Atmospheric Hypersonic Flight

Organization

The JTOH organizationally is located in the Office of the Deputy Undersecretary of Defense for Science & Technology (ODUSD(S&T)) under the Director, Defense Research & Engineering. The JTOH has been organized to best meet its purpose while most effectively leveraging existing management structures and personnel. The JTOH is designed to be a lean organization that efficiently leverages existing management structures and personnel and is operated as a virtual office.

DoD Hypersonic RDT&E Planning

Hypersonics RDT&E[1] activities in the DoD are planned, integrated, and executed by focusing on providing future capability to the warfighter. Three future capability areas have been defined that guide hypersonics RDT&E,

- ***Strike / Persistent Engagement (SPE)*** **–** achieve precise and scalable effects from the air or surface with global reach, quick reaction, persistence, and significant payload.
- ***Air Superiority / Protection (ASP)*** – prevent or mitigate an adversary's affect on self, the joint force, and the population that the joint force protects thus ensuring freedom of maneuver
- ***Responsive Space Access (RSA)*** **–** get to space, return to earth, then get back to space with aircraft-like operations tempo.

For each hypersonics future capability area, a set of technology products are identified that will enable that capability. Technology products are deliverables of the RDT&E process and therefore can be tracked and evaluated. Technology products form the basis of the hypersonics RDT&E technology roadmaps. Within each technology product there may be many programs/projects which contribute to that technology product.

NASA Hypersonics Research

The DoD and NASA have a long history in close collaborative activities in hypersonics RDT&E. Today, NASA's Aeronautics Research Mission Directorate (ARMD) Fundamental Aeronautics Program (FAP) directs a Hypersonics Project area to conduct long-term, cutting-edge research in the core competencies of the hypersonic regime. The goal of the FAP Hypersonics Project is to produce knowledge, data, capabilities, and design tools at the foundational, discipline, multidiscipline, and systems levels. The FAP Hypersonics Project has defined two high-payoff NASA-unique mission areas to focus its fundamental research activities: Highly Reliable Reusable Launch Systems (HRRLS) and High Mass Mars Entry Systems (HMMES). A key objective of the Hypersonics Project is to develop methods and tools that adequately model fundamental physics, and allow credible, physics-based optimization for future operational hypersonic vehicle systems of the two classes identified above.

Although the focus of the NASA Hypersonics Project is on the NASA-unique HRRLS and HMMES systems, the hypersonics technologies that enable these systems are common to the hypersonic technologies that enable DoD-specific hypersonics systems. Therefore, there is a multitude of ongoing DoD- NASA collaboration on hypersonics research. Examples of ongoing DoD-NASA collaboration on hypersonics research are the X-51A scramjet engine demonstrator,

[1] For the purposes of this report "Research, Development, and Test and Evaluation" is defined as follows. "Research" is defined to extend from basic research, which is the systematic study in pursuit of fuller knowledge or understanding, to applied research and advanced development, which is the systematic study to gain and apply knowledge toward the creation of practical materials, devices, and systems. "Development" is defined as programs with goals to integrate technologies and subsystems that have been demonstrated in a relevant environment into a complete system which could be acquired. Finally, "Test and Evaluation" (T&E) is defined as tests and experiments in support of research development and acquisition of systems, including developmental and operational testing. T&E includes not only significant ground test facilities (e.g., wind tunnels, engine test stands, etc.) but also software, numerical simulation, and systems test infrastructure and support.

the US-Australia Hypersonic International Flight Research Experimentation (HIFiRE) project, the DARPA/AF Falcon program, and the DoD Next Generation Launch planning activities.

Joint Technology Office on Hypersonics Roadmaps

The hypersonic RDT&E roadmaps for the DoD are organized by the three hypersonic future capability areas as defined above. For each hypersonic future capability area, there is a Technology Product roadmap and a Technology Transition roadmap. In addition, there are similar roadmaps for the cross-cutting areas of Facilities and Test Resources, and Basic Research.

The Technology Product roadmaps show the technology products that will help to enable a respective future capability area. The roadmap shows technology products, the DoD Military Departments/Defense Agency Program Elements (PE) and funding for Fiscal Years 2007-2009. Milestones on the Technology Product roadmaps represent achievement of a Technology Readiness Level (TRL) for a particular product (an explanation of TRL is provided in the appendix). The actual event that signifies achievement of a specific TRL for a specific technology product may be different for different technology products. Following each Technology Product roadmap are brief descriptions of the technology focus for that product. If applicable, specific projects associated with the technology product are identified.

The Technology Transition roadmap shows how the current technology products and technology demonstrations can transition to potential future demonstrations and applications. Similarly, following each Technology Transition roadmap are brief descriptions of the ongoing technology demonstrations and the potential future demonstrations and applications. Also noted on the roadmap and descriptions are the technology products which contribute to the current demonstrations and the future potential demonstrations and applications.

Strike/Persistent Engagement Roadmaps

The Strike/Persistent Engagement Capability area seeks to achieve precise and scalable effects from the air with global reach, quick reaction, persistence, and significant payload. This capability area includes three attributes related to high speed / hypersonics:

Time Sensitive Regional Strike – This attribute reflects the performance characteristics of high speed / hypersonic cruise standoff weapons with nominal range of 600-1000nm, capable of precision engagement of high-payoff, time-sensitive, fixed/relocatable, moving, and deeply buried targets within 10-20 minutes of tasking. Technology availability for this attribute is projected to be approximately 2018.

Time Sensitive Global Strike – This attribute reflects the performance characteristics of boosted hypersonic glide weapons with global range, capable of precision engagement of high-payoff, time-sensitive, fixed/relocatable, moving, and deeply buried targets within ~60 minutes of tasking. Technology availability for this attribute is projected to be approximately 2015-2020.

Responsive Global Force Delivery with Persistence – This attribute reflects the far term vision of fully reusable hypersonic aerospace platforms capable of global reach and repeatable sortie generation for persistent and sustained force application. Technology availability for this attribute is projected to be post 2020.

Strike/Persistent Engagement Technology Product Roadmap

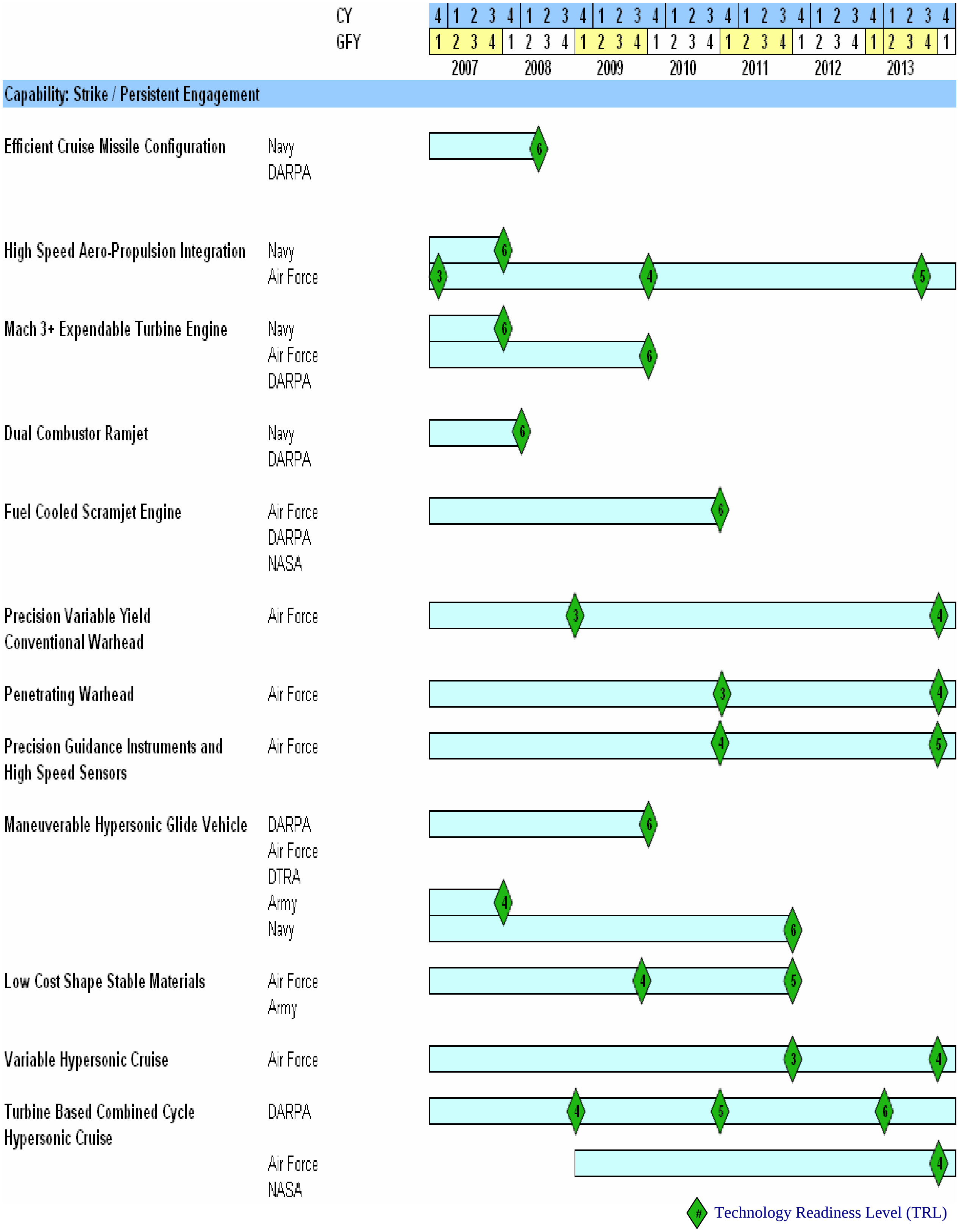

Figure 1 SPE Technology Product Roadmap

Strike/Persistent Engagement Technology Products

Efficient Cruise Missile Configuration: Efficient cruise aero-configuration with affordable construction and payload integration. Supports supersonic Mach 3+ class missiles in near term, and hypersonic Mach 6+ class missiles in mid to far term. Major programs supporting this product include RATTLRS and HyFly.

High Speed Aero-Propulsion Integration: Integrated system (vehicle, inlet, engine, exhaust) ground and flight demonstrations to validate overall system performance. Includes aerodynamic configuration and integrated structures for both expendable and reusable applications in the high-speed flight environment. The major program supporting this product includes RATTLRS. This product also leverages the *Hypersonic Aero-Propulsion* integration product in the Responsive Space Access capability area.

Mach 3+ Expendable Turbine Engine: Supports high speed standoff weapon for precision fixed and mobile target engagement. Efficient expendable turbine engine capable of Mach 3-4 extended range operation. Major programs supporting this product include RATTLRS and HiSTED. This product is also leveraged by the *High Mach Turbine Propulsion* product in the Operationally Responsive Space capability area.

Dual Combustor Ramjet: Supports hypersonic regional standoff weapon for precision fixed and deeply buried target engagement. Efficient expendable ram/scram engine capable of Mach 5-6 extended range operation. Includes liquid hydrocarbon airbreathing engine technology, with high-temperature metallic and composite materials and structures for passive cooling. The major program supporting this product is HyFly.

Fuel Cooled Scramjet Engine: Supports hypersonic regional standoff weapon for precision fixed and deeply buried target engagement. Efficient expendable ram/scram engine capable of Mach 6+ extended range operation. Includes liquid hydrocarbon airbreathing engine technology, with high-temperature actively cooled metallic structures and endothermic fuel thermal management. The major program supporting this product is X-51A. This product is also leveraged by the *Reusable RBCC 2nd Stage* product in the Responsive Space Access capability area.

Precision Variable Yield Conventional Warhead: Supports flexible lethality against a variety of targets with controlled collateral damage for any of the high speed weapon systems described herein. This product includes tailored blast pulse to maximize or minimize target coupling, selectable mode energetics (deflagrate or detonate), hardened miniature fuzing, and energetic warhead structures that contribute to blast energy.

Penetrating Warhead: Supports lethality against hardened and deeply buried targets for any of the high speed weapons systems described herein. This product includes survivable microelectronic fuze technology, validated modeling and simulation of harsh environments and penetration hydromechanics, and explosive lethality and thermal stability.

Precision Guidance Instruments and High Speed Sensors: Supports boost-glide hypersonic weapon for precision fixed and deeply buried target engagement. This product develops affordable guidance instruments that provide adequate accuracy to engage prompt global strike (PGS) targets, including relocatable and moving targets via in-flight datalink and active onboard target identification and location update. This product also includes high temperature sensors and apertures, miniature low-power sensor systems, precision sensor pointing through hypersonic boundary layers, and aperture performance through plasma sheaths. Major programs supporting this product include Falcon and Conventional Strike Missile (CSM).

Maneuverable Hypersonic Glide Vehicle: Supports boost-glide hypersonic weapon for target engagement including precision fixed and deeply buried targets. This product includes high lift/drag hypersonic configuration development, aerothermodynamic analysis techniques, and adaptive guidance and control. This product also includes technology to dispense weapon payloads from a Maneuverable Hypersonic Glide Vehicle. Major programs supporting this product include Falcon and CSM. Congressional Add: Advanced Hypersonic Weapon, FY07, FY08

Low Cost Shape Stable Materials: Supports boost-glide hypersonic weapon for precision fixed and deeply buried target engagement. This product focuses on affordable low ablation thermal protection approaches for controlled long duration hypersonic flight. Material development is conducted via high temperature ground test facilities. Congressional Add: Advanced Hypersonic Weapon, FY07

Variable Hypersonic Cruise Aeroconfiguration: Supports far term vision of reusable hypersonic strike platform. This product includes fundamental hypersonic flight research and quantitative technology assessment for potential breakthroughs in propulsion, materials, and structures. Major programs supporting this product include HIFiRE and Falcon.

Turbine Based Combined Cycle Hypersonic Cruise: Supports far term vision for reusable hypersonic strike platform. This product includes development of inlet and exhaust components via scale ground testing. Major programs supporting this product include FACET. This product is also leveraged by the *HTOL TBCC Integration* product in the Responsive Space Access capability area.

Strike/Persistent Engagement Technology Transition Roadmap

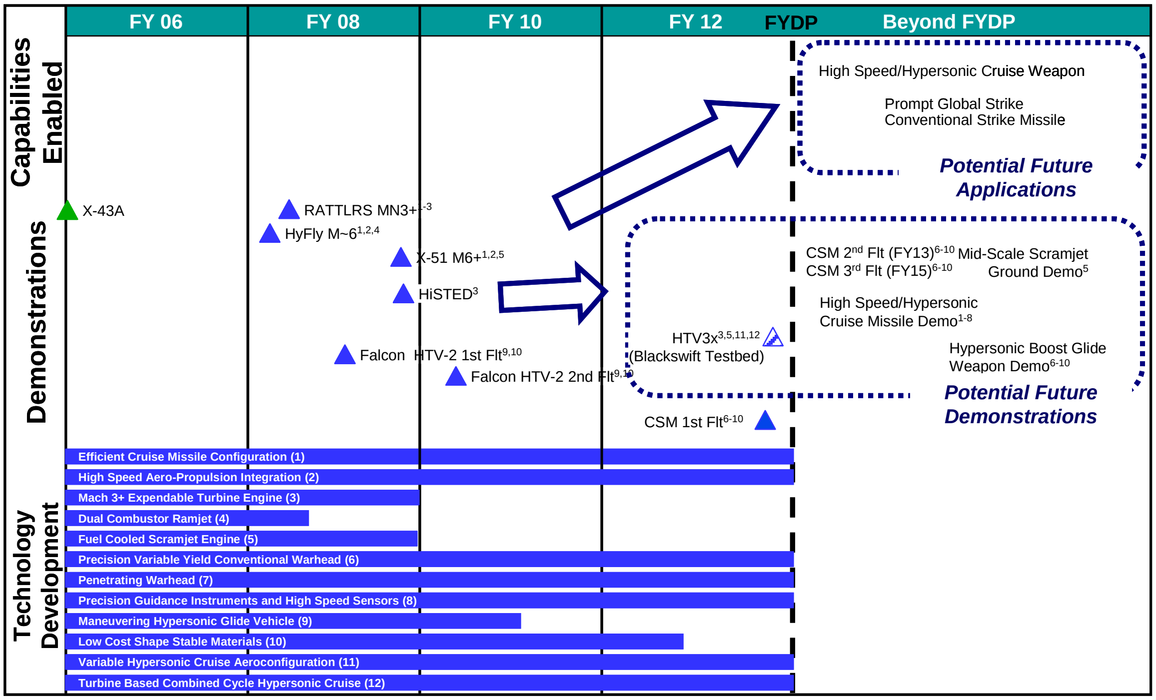

Figure 2 SPE Technology Transition Roadmap

Strike/Persistent Engagement Technology Transition Demonstrations

Revolutionary Approach to Time-Critical Long Range Strike (RATTLRS): Flight demonstration of a Mach 3+ cruise missile vehicle. Includes payload integration and high Mach turbine capable of transonic acceleration and 15 minute Mach 3+ cruise duration. One full scale powered flight scheduled for Feb 2008.
Technology Products: *Efficient Cruise Missile Configuration, High Speed Aero-Propulsion Integration, Mach 3+ Expendable Turbine Engine*

Hypersonic Flight (HyFly): HyFly demonstrates sustained Mach 6 flight in a weapon configuration. Includes an uncooled refractory carbon-carbon Dual Combustor Ramjet capable of Mach 3.3 – 6.0. The first full-scale powered flight was conducted September 25, 2007. The second full-scale powered flight was conducted on January 16, 2008.
Technology Products: *Efficient Cruise Missile Configuration, High Speed Aero-Propulsion Integration, Dual Combustor Ramjet*

X-51A: Flight demonstration of a fixed geometry hydrocarbon fueled scramjet. Includes a fuel cooled scramjet engine in a waverider airframe configuration for Mach 4.5 – 7.0. Four flights with maximum flight duration of 12 minutes, scheduled for 2009.
Technology Products: *Efficient Cruise Missile Configuration, High Speed Aero-Propulsion Integration, Fuel Cooled Scramjet Engine*

High Speed Turbine Engine Demonstrator (HiSTED): Turbine engine technology development for Mach 3-4+ applications, including high temperature low cost turbo-machinery, high temperature bearings and lubrication, and cooled cooling air/high heat sink fuel thermal management. Engine system ground demonstrations scheduled for April and September 2008.
Technology Products: *Mach 3+ Expendable Turbine Engine*

HTV-2 (Falcon): Flight demonstration of hypersonic boost-glide vehicle with high aerodynamic efficiency aero-configuration, carbon-carbon aero-shell design for manufacturability, and advanced GPS guidance. Two flight demonstrations using Minotaur IV booster in March 2009 and July 2009.
Technology Products: *Maneuverable Hypersonic Glide Vehicle, Low Cost Shape Stable Materials*

Conventional Strike Missile (CSM): Flight demonstration of an advanced boost-glide weapon system. Includes Minotaur rocket boost, biconic hypersonic glide vehicle, advanced GPS guidance, and conventional payload integration. Flight demonstrations will prove maneuverable long range endoatmospheric glide with advanced TPS and precision terminal accuracy. Three demonstration flights are planned for 2012-1015.
Technology Products: *Precision Variable Yield Conventional Warhead, Penetrating Warhead, Precision Guidance Instruments and High Speed Sensors, Maneuverable Hypersonic Glide Vehicle, Low Cost Shape Stable Materials*

Strike/Persistent Engagement Potential Future Demonstrations

Falcon HTV-3x (Blackswift Testbed): Repeatable flight demonstration of a Mach ~6 aircraft. Integrated turbine-based combined cycle propulsion system includes an advanced inward turning inlet, HiSTED turbine, and X-51 derived fuel cooled dual mode scramjet. Based on current progress to date and potential for future transition to operational USAF capabilities, DARPA and USAF have signed a Memorandum of Understanding (MOU) to pursue this high-risk, high-payoff technology in the Blackswift program.
Technology Products: *Mach 3+ Expendable Turbine Engine, Fuel Cooled Scramjet Engine, Variable Hypersonic Cruise Aeroconfiguration, Turbine Based Combined Cycle Hypersonic Cruise*

High Speed / Hypersonic Cruise Missile: Full capability weapon system demonstration including air launched weapon with Mach 3-6+ cruise up to 1000nm, on-board sensor employment for guidance and target acquisition, and terminal engagement of fixed targets. Includes additional ground test series of tailored lethality and penetrating warheads. This demonstration will build on the flight test experience of RATTLRS, HyFly, and X-51A and integrate other munition, connectivity, and sensor technologies into a weaponized flight demonstration.
Technology Products: *Efficient Cruise Missile Configuration, High Speed Aero-Propulsion Integration, Mach 3+ Expendable Turbine Engine, Dual Combustor Ramjet, Fuel Cooled Scramjet Engine, Precision Variable Yield Conventional Warhead, Penetrating Warhead, Precision Guidance Instruments and High Speed Sensors*

Mid-Scale Scramjet Ground Demonstration: Ground demonstration of fuel cooled dual mode scramjet propulsion system scaled up to 5X-10X of the X-51 thrust class for larger weapons and space lift applications. Includes broadening of the operational Mach envelope to 3.5-8.
Technology Products: *Fuel Cooled Scramjet Engine*

Hypersonic Boost-Glide Weapon Demo: Potential follow-on to the Conventional Strike Missile demonstration, incorporating advanced carbon-carbon nose tip and aeroshell construction, high aerodynamic efficiency aero-configuration, advanced weapon integration including penetrator warheads, and active sensor/seeker components for robust autonomous guidance.
Technology Products: *Precision Variable Yield Conventional Warhead, Penetrating Warhead, Precision Guidance Instruments and High Speed Sensors, Maneuverable Hypersonic Glide Vehicle, Low Cost Shape Stable Materials*

Strike/Persistent Engagement Potential Future Applications

High Speed / Hypersonic Cruise Missile: The high speed / hypersonic cruise missile can support various levels of capability across the reach and responsiveness trade space. This trade space may be organized into supersonic and hypersonic speed regimes and medium to long range. The following table lists typical performance attributes for cruise weapons:

	Length (in)	Launch Weight (lb)	Cruise Speed / Altitude (ft)	Range (nm) / Time (min)
Supersonic Med-Range	168 to 218	2,200 to 3,000	Mach 4 / 80,000	250 / 7 and 500 / 13
Supersonic Long-Range	154	1,833	Mach 3.5 / 80,000	750 / 21 and 1000 / 29
Hypersonic Med-Range	168	2,200	Mach 7 / 95,000	250 / 5 and 500 / 9
Hypersonic Long-Range	168 to 300	2,800 to 5,000	Mach 7 / 95,000	750 / 12 and 1000 / 16

The high-speed / hypersonic missile would be launched at subsonic speeds and at altitudes between 30,000 and 40,000 ft. Targeting information would be provided to the launch aircraft where the data would be uploaded to the weapon. After launch, the missile will accelerate to cruise conditions shown above. In-flight guidance would rely upon integrated GPS/INS and possibly passive sensing. For both missiles, descent would occur rapidly into the target area for either a direct or a submunition attack. If using a submunition payload, the missile would decelerate to transonic or subsonic speeds prior to autonomous submunition deployment. If using a direct attack (unitary warhead) payload, the missile would use GPS and/or an active terminal sensing, allowing for impact velocities ranging from 1,000 to 4,000 feet per second.

Prompt Global Strike/Conventional Strike Missile: The maneuverable hypersonic boost-glide weapon system capability is to deliver precision conventional effects with global reach (~9000nm) within one hour. The weapon system could be boosted by excess and/or commercial motors, or perhaps via future responsive space lift platforms. In either case, the majority of the

flight trajectory would be endoatmospheric and have sufficient maneuverability to avoid overflight of restricted airspace (600-3000nm cross-range capability).

Delivered payload is on the order of 1000-2000lbs, with flexible kinetic and non-kinetic configurations including multiple precision guided sub-munitions, unitary penetrating munitions, and/or sensor packages. Physical characteristics of the hypersonic vehicle are 12 feet length, 4 feet width, and up to 3500lb weight. The vehicle speeds are nominally Mach ~24 reentry, a Mach 10-15 glide, and Mach 4 terminal impact.

Air Superiority/Protection Roadmaps

The Air Superiority/Protection Capability (ASP) seeks to prevent or mitigate an adversary's affect on the joint force and the population that the joint force protects thus ensuring freedom of maneuver. While there are Department RDT&E investments in a wide variety of technologies for ASP capabilities, the RDT&E investments for hypersonics technology in this capability area are limited at present time to the Missile Defense Agency (MDA).

Air Superiority/Protection Technology Product Roadmap

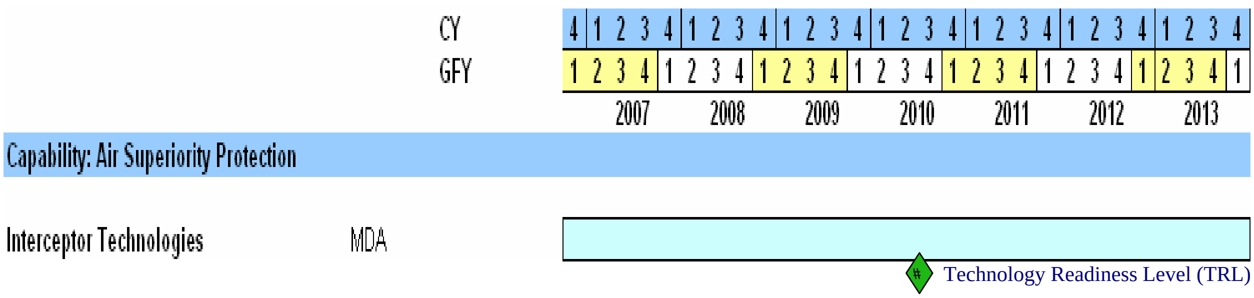

Figure 3 ASP Technology Product Roadmap

Air Superiority/Protection Technology Products

Interceptor Technologies: New capabilities for Boost, Midcourse, and Terminal Defense to counter new and evolving threats and countermeasures. These technologies provide miniaturized components to enable next generation small and lightweight kill vehicles and space products. They provide robust intercept capabilities in the absence of a priori target information, enhanced target detection and tracking by the kill vehicle, and improved lethality in the presence of endgame countermeasures. Interceptor technologies seek to deliver advanced components and subsystem technologies to enable next generation interceptors and discrimination approaches as well as upgrade and enhance existing kill vehicles to allow them to keep pace with the evolving threat. In addition, the ITP develops new system concepts that defeat evolving threats and countermeasures. Projects included are Air Launched Concepts (Air Launched Hit-to-Kill, Network Centric Airborne Defense Element (NCADE)) and Agile Kill Vehicle.

Responsive Space Access Roadmaps

The Responsive Space Access capability area seeks to achieve on-demand theater force projection, anywhere through responsive deployment of flexible ground, information & space capabilities for the theater commander. Hypersonics is critical to solving the space part of this capability to generate on-demand, reusable affordable space access. This encompasses space launch vehicles able to place military payloads into or through space for global communications, ISR, space operations, point-to-point cargo delivery or weapons delivery repeatedly, on-demand.

Hybrid Responsive Space Access – In the near term, hybrid space access encompasses a non-air breathing (i.e., rocket) propulsion, launch on demand, reusable rocket and an expendable upper stage – thus the term hybrid. Objectives are to reduce space access cost by at least two-thirds by reducing the "expendable" part of space launch and adding most-weather capability, 8-hour callup, 24-48 hour turn time, and 0.995 reliability on the vehicle. Initial objectives focus on a 250 sortie reusable launch vehicle (RLV) with a 100 sortie propulsion system. The Reusable Launch Vehicle first stage would launch vertically, fly to Mach 5 to 7 at 150,000+ feet, launch the upper stage, and then autonomously return to base and land like an aircraft. It is essentially a hypersonic rocket-plane. Many of the RLV supporting technologies also support Strike/Persistent Engagement's cruise missile and maneuverable hypersonic glide vehicle concepts.

Fully Reusable Responsive Space Access – In the far term, to achieve greater cost and reliability improvements, responsive space access must move to fully reusable systems. True aircraft-like operations could be achieved with 12-24 hour turn time, 4-hour callup, 10 times reduction in cost, and 0.999 reliability. Reusable air breathing hypersonic scramjet technologies are the key to achieving this capability. Responsive space access leverages the expendable scramjet work in Strike/Persistent Engagement and focuses on reusable scramjets. A scramjet and rocket combined cycle vehicle would provide a reusable upper stage to replace the expendable second stage on hybrid vehicle above, while a high-Mach turbine and scramjet combined cycle would provide horizontal takeoff and landing replacing the RLV first stage.

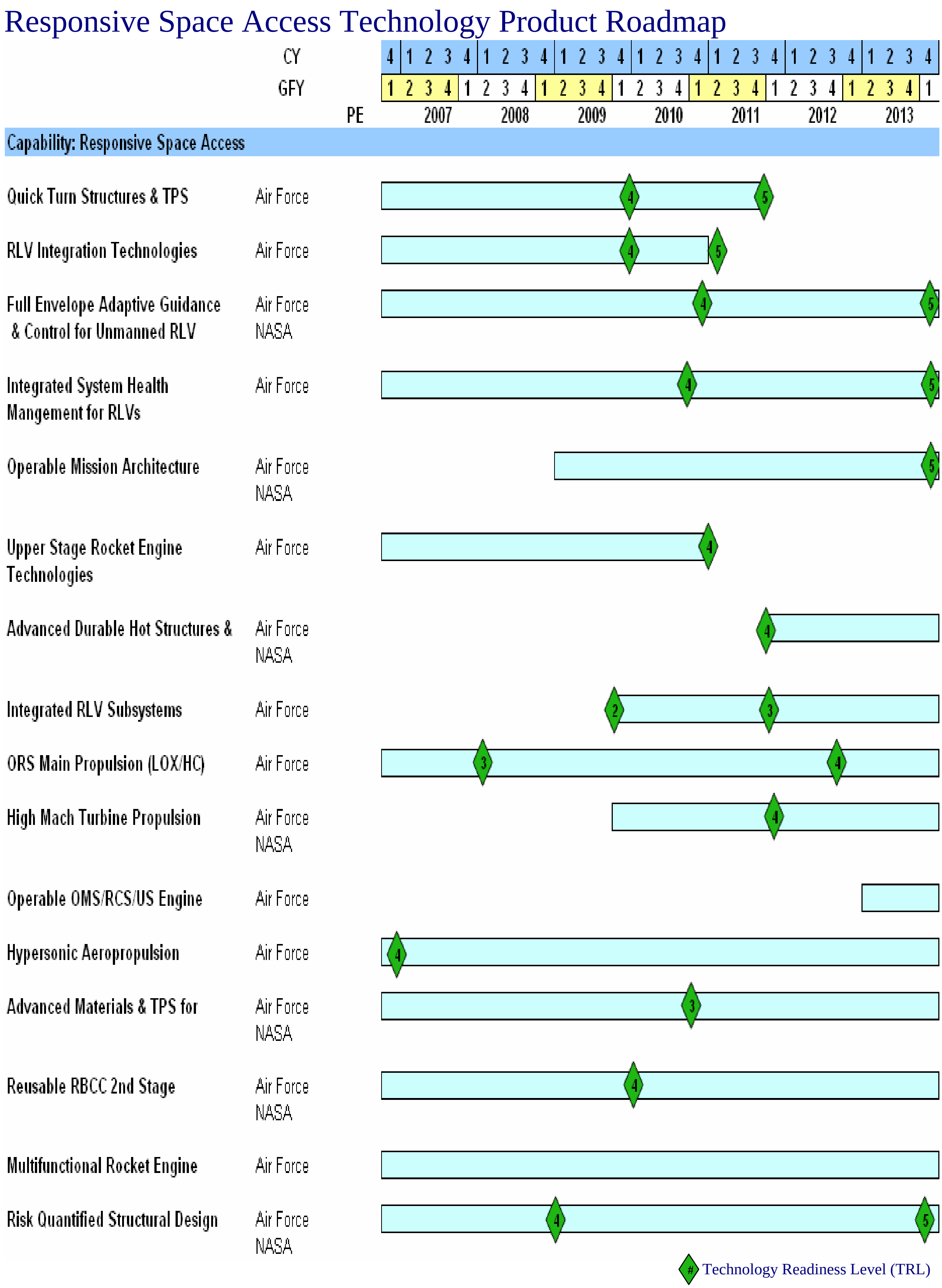

Figure 4 RSA Technology Product Roadmap

Responsive Space Access Technology Products

Quick Turn Structures & TPS (Thermal Protection Systems): External thermal management for reusable hypersonic vehicles up to Mach 8. Uses mechanically attached acreage TPS to Mach 8 and leading edge TPS to Mach 20 to gain reusability. Focus is on the durability of high temperature structures especially when exposed to large thermal peaks with short soak time. Mechanically attached TPS reduces maintenance and turn time to 24-48 hours. Leading edge TPS provides thermal margin for maneuverability and greater cross range.

RLV Integration Technologies: Reusable Mach 8 rocket plane design, CFD tools, 6DOF thermal and pressure load models, wind tunnel experiments, and ground operability simulations build the tool set for the design community. Explore trades between lift/drag, thermal, pressure/Mach number, g-loading, fineness, maneuverability, operability, cost, etc.

Full Envelope Adaptive Guidance & Control for Unmanned RLV: Supports sub/super/hypersonic unmanned vehicles. Allow autonomous operation of hypersonic UAV. Provide adaptive response flight control modifications to in-flight actuator failures for both pre-planned and updated alternatives and to generate new flight path alternatives real time to increase survivability to 0.999.

Integrated System Health Management for RLVs: Supports sub/super/hypersonic unmanned vehicles. ISHM provides real-time system health monitoring and failure reporting to AG&C for in-flight trajectory reshaping. Integrate real-time sensing and prognostics to increase reliability to .997. Minimize un-planned maintenance events to achieve rapid turn time.

Operable Mission Architecture: Reusable Mach 7 Rocket Plane Flight Experiments. Development and validation of operability driven design methodologies, ground operations predictions, rapid mission planning tools, integrated sub-system modeling, thermal management, integrated health management, and range operations concepts.

Upper Stage Rocket Engine Technologies: Expendable rocket upper stages to reduce mass fraction of system and decrease first stage size. The upper stage rocket engine will use the same hydrocarbon fuel as the first stage to reduce operations costs and system complexity.

Advanced Durable Hot Structures & TPS: Extend thermal stability & oxidation resistant materials and coatings to Mach 20 for both composite and metal structures. Expand substrate failure detection and repair technologies. Expand all weather-envelope to 90% of weather phenomena at Kennedy. Reduce weight and maintenance turn time, increase durability, and longevity of hot structures. Create new durable TPS materials to enable vehicles to fly and maneuver faster, be able to withstand exposure to increasingly extreme environments, and be more responsive, durable, and survivable. System goals to be met include rapid ground turn around and near all weather operations. Milestone goals are focused on the development of materials with higher temperature and pressure capability over longer and more severe mission environments as well as extending durability and life. Included is development of a suite of multiple materials systems with advanced properties which includes defining trades and design rules for warm and hot structural materials (both hot composites and warm metals); development of durable materials and efficient integration for high heat flux leading edges;

development of load bearing conformal cryogenic tank materials; and defining materials and processes to reduce TPS requirements where possible.

Integrated RLV Subsystems: Extend subsonic subsystem technologies into hypersonic speed regime. Develop high specific-power density, high temperature actuators. Expand immunity from electromagnetic interference: electric actuator and controller unaffected by EMI. Develop light-weight, low-power, high-temperature sensors. Integrate vehicle management, control system, and health management.

ORS Main Propulsion (LOX/HC): Reusable 250,000 lb thrust, 100 mission life hydrocarbon fueled rocket brass board. The reusable first stage rocket technologies for Hybrid provide the reusable rocket portion of combined cycle for RBCC rocket/scramjet & TBCC high speed turbine/ramjet/scramjet.

High Mach Turbine Propulsion: Ground demonstration of a robust turbine engine capable of rapid acceleration through transonic speeds to Mach 4+. Explore high performance exhaust system over broad Mach number range. Determine bearing/lubricant robustness in high temperature environment. Integrate thermal management of propulsion and vehicle. Determine augmentor operability.

Operable OMS/RCS/US Engine: Long life 100lbf class thruster ground experiment with 200 mission life and operable catalyst/igniter using non-toxic propellants. Explore long life operable high temperature monopropellant catalyst substrate, alternate ignition, and decomposition techniques.

Hypersonic Aero-propulsion Integration: Fundamental research hypersonic flight experimentation (HIFiRE), sub-scale flight experiment (SCRAMBLE) of a reusable scramjet vehicle, and large scale API ground demonstration. Explore aero-propulsion efficiency, reusability, durable light-weight hot structures, and vehicle integration.

Advanced Materials & TPS for Structures: Create new durable TPS materials for rapid turn & most-weather operations. Define trades and design rules for warm and hot structural materials (both hot composites and warm metals) to reduce TPS requirements where possible. Durable materials & efficient integration for high heat flux leading edges. Load bearing conformal cryogenic tank materials. Define materials and processes that enable non-parasitic TPS.

Reusable Rocket-Scramjet Combined Cycle (RBCC) 2nd Stage: Medium scale rocket based scramjet combined cycle ground demo. Encompasses air breathing-rocket ignition transients and lightweight air breathing/rocket propulsion vehicle integration. Efficient inlet/exhaust nozzle performance over wide range of flight conditions is essential. The objective is reusable high-mach scramjet performance from mach 4 to 14.

Multifunctional Rocket Engine: Large scale ground experiments with integrated propulsion health management. Advanced propulsion cycles, materials, multi-mode rocket booster, and advanced hydrocarbon fuel development. Provides the rocket component feed for reusable scramjet concepts.

Risk Quantified Structural Design: Develop processes and procedures for delivering an airframe that has the necessary structural integrity and reliability to meet the design life, without having to perform the traditional destructive full-scale tests. Develop specifications to combine system structural integrity and reliability requirements. Methods to allocate system requirements down to components.

Responsive Space Access Technology Transition Roadmap

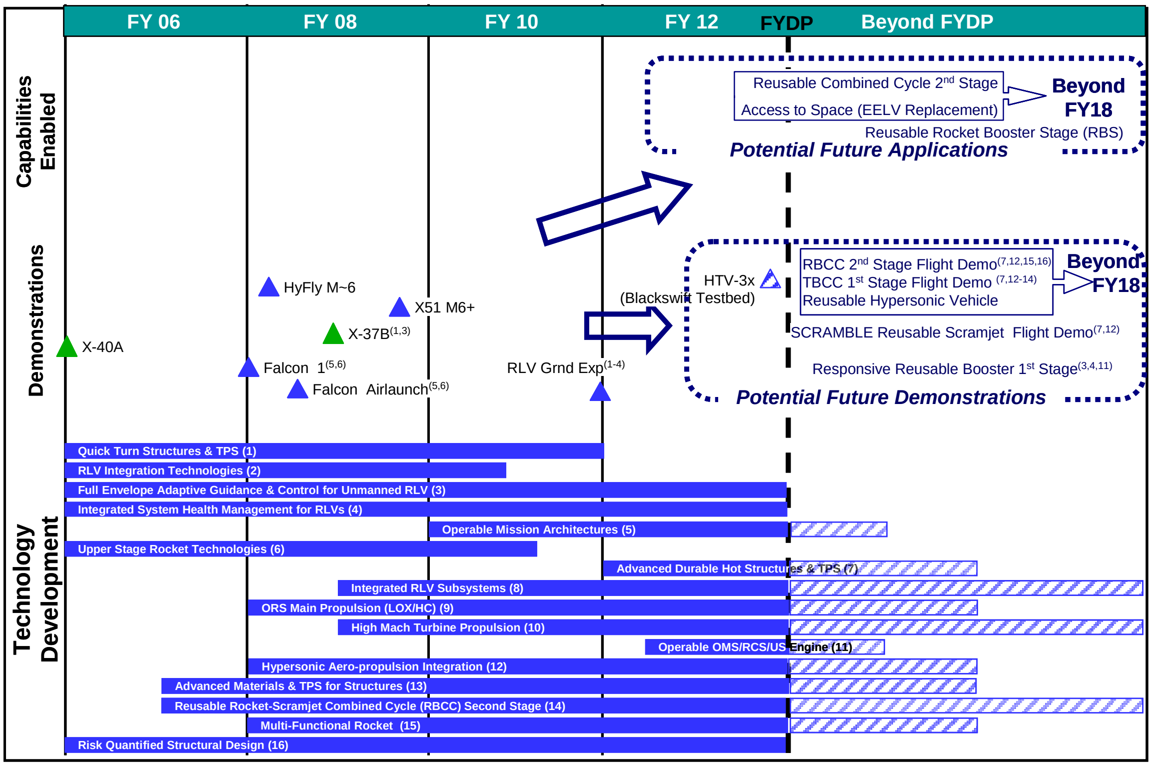

Figure 5 RSA Technology Transition Roadmap

Responsive Space Access Technology Transition Demonstrations

Hypersonic Flight (HyFly): HyFly demonstrates sustained Mach 6 flight in a weapon configuration. Includes an uncooled refractory carbon-carbon Dual Combustor Ramjet capable of Mach 3.3 – 6.0. The first full-scale powered flight was conducted September 25, 2007. The second full-scale powered flight was conducted on January 16, 2008.
Technology Products: See Strike/Persistent Engagement Roadmaps for Technology Products

X-37B: Flight demonstration of a reusable space plane in 2009. X-37B is a lifting body reentry vehicle launched on a Delta II class expendable rocket into low-earth orbit. It will enter orbit, open its bay to conduct experiments in space, and then return to base landing horizontally.
Technology Products: *Quick Turn Structures/TPS, Full Envelope Adaptive Guidance and Control for RLVs, Advanced Durable Hot Structures & TPS.*

X-51A: Flight demonstration of a fixed geometry hydrocarbon fueled scramjet. Includes a fuel cooled scramjet engine in a waverider airframe configuration for Mach 4.5 – 7.0. Four flights with maximum flight duration of 12 minutes, scheduled for 2009.
Technology Products: See Strike/Persistent Engagement Roadmaps for Technology Products

Falcon 1 and Airlaunch: The Falcon 1 expendable ground launch rocket and the air launch rocket are experiments to look at reducing launch infrastructure to reduce cost and explore operability. Falcon 1 uses low cost entrepreneurial innovation to build a rocket engine able to lift about 950 lbs into low earth orbit. The commercial follow-on will combine engines to lift 10K lbs at ½ the cost of the retiring Delta II launcher. Airlaunch looked at reducing range costs and providing operations flexibility by launching a liquid rocket from a C-17. An operations experiment, it is not scalable to payload sizes of EELV.
Technology Products: *Operable Mission Architecture, Upper Stage Rocket Engine Technologies*

Responsive Launch Vehicle (RLV) Ground Experiment: Ground experiments will mature technologies through 2014 focusing on light weight structures, load-bearing cryo tanks, mechanically attached thermal protection, integrated vehicle health management, adaptive guidance and control, operability, and aerodynamic design trades for a responsive reusable rocket plane.
Technology Products: *Quick Turn Structures & TPS, RLV Integration Technologies, Full Envelope Adaptive Guidance & Control for Unmanned RLVs products to TRL 5, Integrated System Health Management for RLVs*

Falcon HTV-3x (Blackswift Testbed): Repeatable flight demonstration of a Mach ~6 aircraft. Integrated turbine-based combined cycle propulsion system includes an advanced inward turning inlet, HiSTED turbine, and X-51 derived fuel cooled dual mode scramjet. Based on current progress to date and potential for future transition to operational USAF capabilities, DARPA and USAF have signed a Memorandum of Understanding (MOU) to pursue this high-risk, high-payoff technology in the Blackswift program.
Technology Products: See Strike/Persistent Engagement Roadmaps for Technology Products

Hydrocarbon Boost Engine Demo: Completes brass board engine tests of reusable ORS Main Propulsion demonstrating a 100 use engine at 250,000 lbf thrust. TRL 5 components would transition to reusable rocket engine development program.
Technology Products: *Advanced Durable Hot Structures & TPS, ORS Main Propulsion (LOX/HC)*

Responsive Space Access Potential Future Demonstrations

Responsive Reusable Booster 1st Stage Flight Experiment: AF Space Command's S&T need is to achieve greater responsive and lower cost as they replace EELV and the Delta II class launchers beyond 2018. Reusable Booster adds OMS/RCS/US engines for reentry control, and engine health management to the RLV Ground Experiments. Integrates ISHM and AG&C into one seamless system and carries the RLV technologies to TRL6 ready for tech transition. Focus

now on operable architecture for maintenance and rapid launch. The RBS demonstrator would fly around 2018 to validate technologies for responsive spacelift to support conventional glide munitions, tacsat/opsat insertion, rapid satellite constellation regeneration, and routine launch.
Technology Products: *Full Envelope Adaptive Guidance and Control for Unmanned RLV, Integrated System Health Management for RLVs, Operable OMS/RCS/US Engine*

SCRAMBLE subscale Reusable Scramjet: Leverages the expendable scramjet work of HyFly, X-51A, and Falcon Hypersonic Test Vehicle 3 in Strike/Persistent Engagement to create a hydrocarbon fueled, reusable, Mach 4 - 20, second stage propulsion system. SCRAMBLE combines the expendable work with Hypersonic Aero-propulsion Integration to achieve a reusable scramjet.
Technology Products: *Advanced Durable Hot Structures & TPS, Hypersonic Aero-propulsion Integration*

Reusable Rocket-Scramjet Based Combined Cycle (RBCC) 2nd Stage: Integrates the SCRAMBLE reusable scramjet with the reusable rocket technologies of RLV. A scramjet + rocket combined cycle vehicle would provide a reusable upper stage to replace the expendable on RLV above. Requires development and integration of a single airflow system feeding an engine that will operate as a rocket and as a scramjet depending on speed and altitude. Vehicle would launch off of an RLV, fly as a scramjet from Mach 5 to Mach 20 at 200,000 feet, then cycle into a rocket to complete the space launch mission, returning to earth landing horizontally. RBS and RBCC together provide the technologies for a reusable replacement for EELV. RBCC combines the RBCC product with Advance Materials & TPS for Structures, Integrated RLV Subsystems, and Multi-functional Rocket engines.
Technology Products: *Advanced Durable Hot Structures & TPS, Hypersonic Aero-propulsion Integration, Multifunctional Rocket Engine, Risk Quantified Structural Design*

Turbine-Scramjet Based Combined Cycle (TBCC) 1st Stage: The TBCC is an unmanned horizontal takeoff- horizontal landing Mach 4+ hydrocarbon fueled launch vehicle. TBCC could be a variant of Falcon Hypersonic Cruise Vehicle which would carry the RBCC to Mach 4+ or a reusable rocket to Mach 6, launch the upper stage and return to base. As currently projected, the initial HTV-3x demo will have a reusable airframe but use expendable engines developed in the RATTLERS/HiSTED programs. TBCC would demonstrate a fully reusable propulsion system and aircraft like operations as a replacement for RLV. HTOL TBCC integrates High Mach Turbine Propulsion, Multi-functional rocket, and Multi-functional Conformal Structures.
Technology Products: *Advanced Durable Hot Structures & TPS, Hypersonic Aero-propulsion Integration, Multifunctional Rocket Engine, Risk Quantified Structural Design*

Responsive Space Access Potential Future Applications

Reusable Rocket Booster Stage (RBS): RBS would provide a vertical launch, horizontal landing replacement for the first stage of EELV and provide responsive capability as the follow-on to the Minotaur small launch system as ICBM components are used up. RBS would replace 70% of the expendable system in EELV and provide capability from 3.5 to 60K lbm into low-earth orbit.

Reusable Combined Cycle 2nd Stage: Integrating high temperature materials from Advanced Durable Hot Structures would provide an all rocket reusable and responsive complete system

follow on for EELV. Addition of RBCC rocket plus the reusable SCRAMBLE scramjet capabilities increases payload and adds capabilities for cross range and sortie type intelligence missions not practical with today's expendable launch systems.

Access to Space (EELV Replacement): Addition of the horizontal take-off/horizontal landing (HTOL) TBCC using the Hi-Mach Turbine and Scramjet moves space access beyond EELV. It completes the transformation of US space access capability from an expandable vertical "launch-on-schedule" capability into an aircraft like "launch-on-demand."

Facilities and Test Resources Roadmaps

Hypersonic systems for weapons, advanced aircraft, and access to space platforms will require new and enhanced Test & Facilities Resources in several areas such as modeling and simulation (including computational fluid dynamics), ground testing (wind tunnels, sled tracks, installed-system test facilities), and ultimately flight testing. Testing technologies that produce the hypersonic vehicle environment will be necessary to test and evaluate, through modeling and simulation, ground, and flight testing all aspects of the vehicle including propulsion system, structures and materials, guidance and control, seekers and sensors, warheads and payloads, and weapons delivery techniques and end-game dynamics. At hypersonic speeds, flight testing will challenge existing ground instrumentation systems (e.g., tracking system slew rate limitations, telemetry range limitations, telemetry dropouts due to ionization) and range safety decision making.

Test and Facilities Resources Test Technology Roadmap

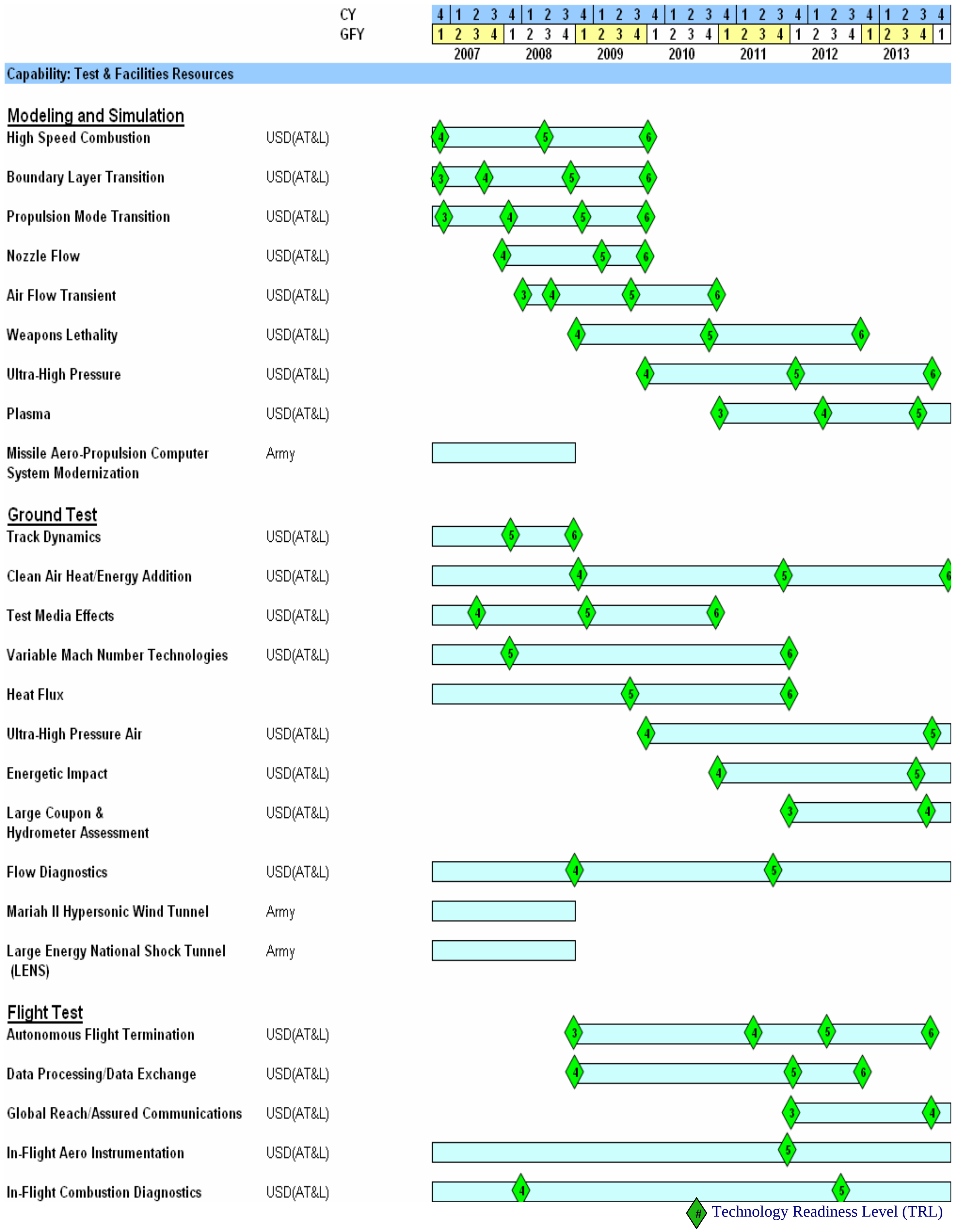

Figure 6 T&FR Test Technology Roadmap

Test Technologies Descriptions

Modeling and Simulation Testing Technologies

High-speed Combustion: Ability to rapidly and accurately predict and analyze combustion dynamics at Mach numbers from 2-14, including atmospheric and combustion chemistry. Includes how a flame is held and propagated in a hypersonic environment through Mach transitions, adapting to atmospheric chemistry and adjusting combustion mix in the various flight regimes, materials analysis for inlets, exhausts, and propulsion components in various flight configurations. Ongoing efforts are Combustion Gas Analysis (CGA) - Hypersonic Engine/Facility Interaction (HEFI) Modeling and Simulation for Hypersonic T&E (M&S HTE).

Boundary Layer Transition: Ability to rapidly and accurately predict and control boundary layer transition at Mach numbers from 2-14, including chemistry, roughness and 3D effects. Includes how high-speed air is created, how the boundary attaches and moves along a surface (and surface effects), and how a vortex is dissipated in a boundary flow. Ongoing efforts include High Pressure Arc Heater (HPAH, Modeling and Simulation for Hypersonic T&E (M&S HTE), Test Media Effects (TME).

Propulsion Mode Transition: Ability to rapidly and accurately simulate mode transition modeling, including capabilities to conduct numerical simulation of time independent mode transition and simulation of ram to scram mode transition. Ongoing effort includes Modeling and Simulation for Hypersonic T&E (M&S THE).

Nozzle Flow: Ability to rapidly and accurately simulate variable Mach airflow using variable geometric structures to constrict or expand the airflow in response to testing requirements. Nozzles represent a method to vary the airflow in a test environment to simulate the velocity transitions. The challenge is to vary the flow but not introduce significant uncertainties (or instabilities) in the flow. Includes High Pressure Arc Heater (HPAH), Plug Nozzle Study (PNS), Test Media Effects (TME), Variable Mach Number Nozzle (VMNN), Micro Fiber Optical Sensors (MFOS).

Air Flow Transient: Ability to rapidly and accurately simulate airflow transients to assess impact on aerodynamics and propulsion using variable geometric structures to constrict or expand the airflow in response to testing requirements. Includes Modeling and Simulation for Hypersonic T&E (M&S HTE), Test Media Effects (TME), Variable Mach Number Test (VMNT, Micro Fiber Optical Sensors (MFOS).

Weapon's Lethality: Ability to conduct full-scale, high fidelity lethality testing up to Mach 12 (4-km/sec) and payload weights to 500 kg. Current capability is limited to 100-kg at Mach 9 (3-km/sec) and 500-kg at Mach 6 (2 km/sec).

Ultra-high Pressure: Ability to develop sufficient understanding of materials properties, chemistry, aerodynamics, and propulsion in an ultra-high pressure environment. This effort requires tasks in high-pressure air creation, materials properties for use in ground test facilities, and instrumentation.

Plasma: Ability to simulate the effects of atmospheric disassociation above Mach 8 and of ionized plasma above Mach 10 on vehicle communications, internal electronics, and chemistry is needed to safely enter flight test. The ability to simulate the effects of plasma on vehicles communications and electronics is needed for safety of flight considerations and provides confidence that telemetry, command self-destruct, operational command and control, RF (including GPS) based navigation systems, and plasma chemistry for structural and propulsion materials will work properly during flight test.

Missile Aero-Propulsion Computer System Modernization: Development and integration of advanced computational architectures for advanced computational fluid dynamic computations in support of the Hypersonic Missile Technology Research and Operations Center (HMTROC).

Ground Testing Technologies

Track Dynamics: Ability to ground test systems and subsystem components at representative speeds in a representative dynamic environment with a test track to include acoustic and mechanical vibration dynamics. Dynamic sensors will be developed under the Microelectromechanical System Shear Stress (MEMS SS) determine the system under test dynamics.

Clean Air Heat/Energy Addition: Methods for energy addition to create high temperature flows required to emulate flight conditions of Mach 8 and above. Activities include Clean Air Heater (CAH) High Pressure Arc Heater (HPAH) –Regenerative Storage Heater (RSH) - Arc heater Aerothermal T&E (AATE).

Test Media Effects: Ability to achieve correlated results for hypersonic propulsion systems across M&S, GT, and FT facilities. Currently there is no capability to quantitatively evaluate and compare test results from different facilities. Projects include Combustion Gas Analysis (CGA) - Hypersonic Engine/Facility Interaction (HEFI) Test Media Effects (TME) - Micro Fiber Optical Sensors (MFOS).

Variable Mach Number Effects: Ability to test aerodynamic and propulsion systems for long time periods in a representative environment with anticipated airflow transitions. Single Mach facilities will provide insufficient risk reduction to warrant flight tests for systems under development. Activities include Plug Nozzle Study (PNS),

Heat Flux: Ability to test aerodynamic and propulsion systems for long time periods for a hypersonic vehicle traveling in the lower atmosphere (high-heat environment). High temperature instrumentation and materials capable of operating in the high temperature, pressure, aggressive chemistry environments anticipated for use in ground test. Activities include High Heat Flux Sensor (HHFS), Micro Fiber Optical Sensors (MFOS).

Ultra High Pressure Air: Investigate materials, chemistry, air creation, and construction techniques for an ultra-high pressure test environment.

Energetic Impact: Ability to test large (100Kg) hypersonic impacts and many small particles for representatively sized test articles. Requires developing mechanism for accelerating weapons to hypersonic speeds, instrumentation, and the associated safety structures to confine the debris.

Large Coupon & Hydrometeor Assessment: Ability to test representative structures in environments for extended periods of time with sufficient transitions to ensure test results can be applied to actual flight conditions. Large (representative) structures behave differently than small material coupons. Ability to conduct adequate hydrometeor impact test capabilities for TPS, external coatings, radomes, infrared windows, etc., system performance

Flow Diagnostics: Ability to assess all air flow parameters in a facility for systems under test including chemistry, species, temperature, pressure, flow, etc. non-intrusively at fidelity necessary to reproduce the testing results at another facility.

Mariah II Hypersonic Wind Tunnel: Develop and Demonstrate technology required to produce extended wind tunnel run time at duplicated hypersonic flight conditions. The effort focuses on the development and integration of a 1MW e-bean system to provide the necessary energy into the wind tunnel flow field to enable longer duration experiments at hypersonic velocities.

Large Energy National Shock Tunnel (LENS): Shock driven wind tunnels capable of producing quiet, clean fully duplicated flight conditions from Mach 4 through 15 at near sea level to 60 km altitude. 1.2 m nozzle exit diameters and 2.4 m test sections permit full scale testing in most cases. Flexible facility supports diverse testing to include aero-optics, aero-propulsion, and free-flight stage separation in a ground test environment.

Flight Testing Technologies

Autonomous Flight Termination: Ability for flight termination transmitter coverage over long distances without complete control by range safety personnel to track all flight parameters, potential debris pattern from system destruct, and instrumentation to obtain all the necessary flight parameters (attitude, altitude, speed, stresses, etc.). Activities include Microelectromechanical System Shear Stress (MEMS SS).

Data Processing/Data Exchange: Ability to process significantly more data at higher data rates from all systems aboard the test vehicle because of the vehicle's higher speed and the more information that is unknown about the performance of systems at hypersonic speeds.

Global Reach/Assured Communication: Ability to provide a scalable and interoperable enterprise architecture system capability to acquire and process flight test data and test simulation from all test ranges. Activities include means to monitor frequency spectrum to insure presence of usable frequencies when required for mission, investigate picosatellite instrumentation platform enterprise command and tracking infrastructure from launch to recovery, and provide a capability to interface to a standardized scalable and interoperable enterprise architecture (EA) system with a real time capability to acquire, process, and distribute vehicle flight test data to designated control central stations across various ranges.

In-flight Aero Instrumentation: Ability to obtain in stream measurements on hypersonic flight vehicles to better validate aerodynamic and combustion models, assure vehicle health during test, and inputs to range safety. Current hypersonic testing is done on an ad hoc basis with intrusive instrumentation relying on (in many cases) limited onboard power and space using instruments that are not optimized and in some cases not suitable for hypersonic testing to obtain scant data. Effort will draw upon other projects including Combustion Gas Analysis (CGA), High Heat Flux Sensor (HHFS), Micro Fiber Optical Sensors (MFOS).

In-flight Combustion Diagnostics: Ability to obtain in stream measurements to assess combustion processes on a vehicle under test. Activity draws upon Combustion Gas Analysis (CGA), High Heat Flux Sensor (HHFS), Micro Fiber Optical Sensors (MFOS).

Test Technology Transition Roadmap

This Test Technology Transition Roadmap combines selected elements from the Modeling and Simulation, and Flight and Ground Test capabilities development. This provides the expected test capability availability for Major Range & Test Facilities Base (MRTFB). It is anticipated that ground and flight test capabilities development will take approximately three years after a Test & Facilities Resources S&T effort is completed.

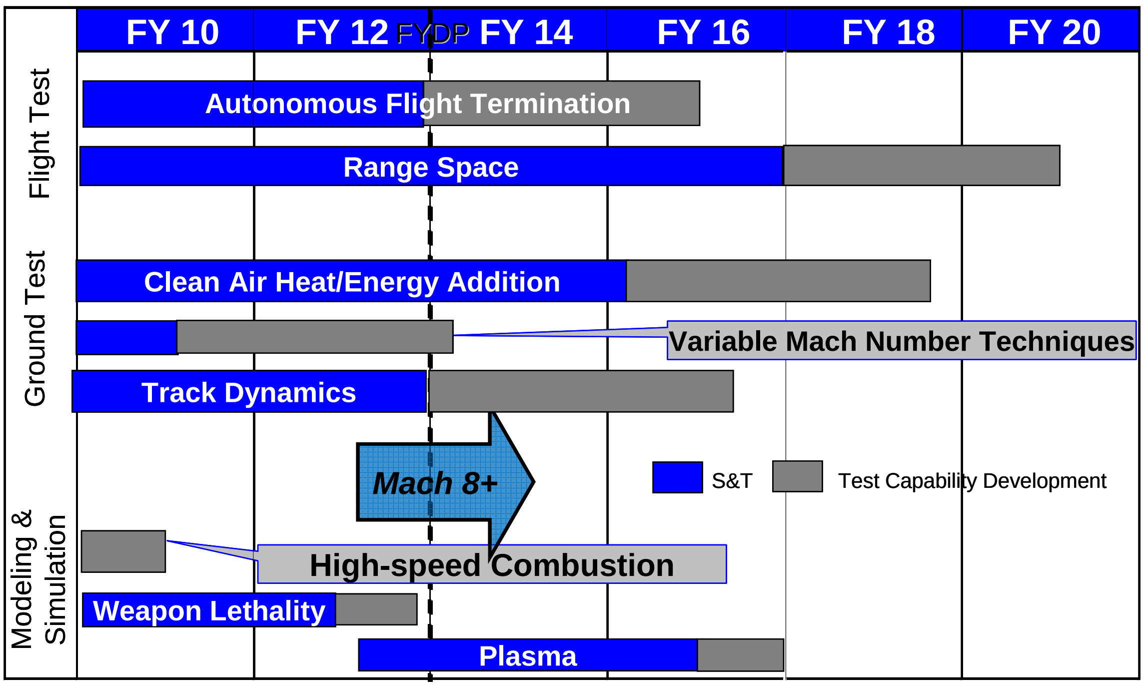

Figure 7 T&FR Test Technology Transition Roadmap

Basic Research Roadmaps

The complexity and severity of the fundamental scientific challenges associated with hypersonic flight increase with increasing Mach number. Basic research is at the core of the Department's hypersonic RDT&E efforts. The Department's basic research charter is systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and has the potential for broad, rather than specific, application. However, to better characterize those areas of basic research which impact hypersonics technology, a National Hypersonics Foundational Research Plan (NHFRP) has been developed by the DoD Military Components and Defense Agencies along with NASA and Sandia National Laboratories. Research challenges include modeling and simulation of the aerothermodynamic environment surrounding the vehicle, development of design methods for high-temperature materials, and characterization, modeling and control of the complex interactions between the flow environment and the vehicle surface. Fundamental research efforts are coordinated in six broad technical areas under the NHFRP as shown on Figure 8.

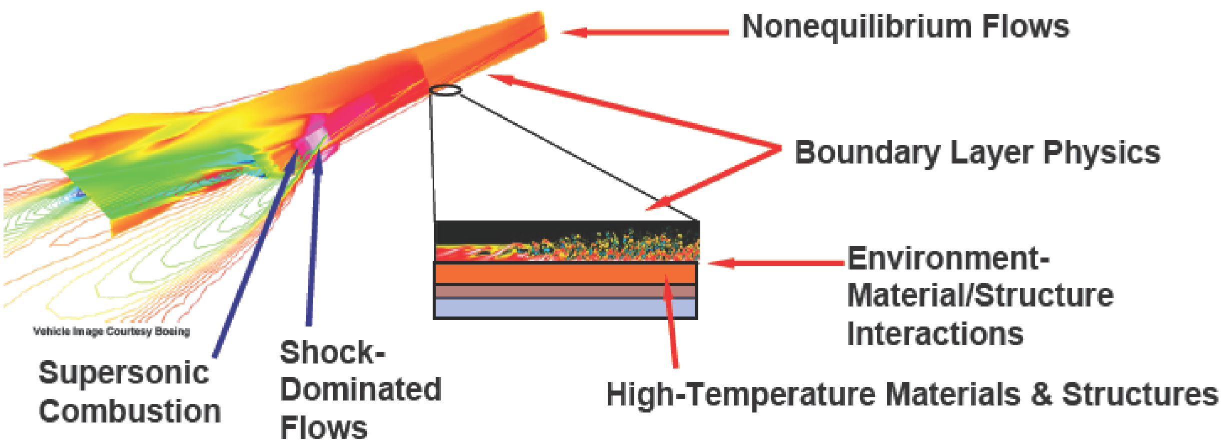

Figure 8 Basic Research Technical Areas

Basic Research Technical Areas

Supersonic Combustion: The most efficient mode of airbreathing propulsion for Hypersonic Mach 6+ flight is supersonic combustion ramjets (scramjets). Research challenges are to achieve complete combustion in approximately 1 ms residence time in the scramjet combustor while minimizing shock losses. Both NASA and the Air Force Research Laboratory have extensive in-house research programs, along with university research through an Air Force Multidisciplinary University Research Initiative (MURI) topic on combined cycle propulsion and the NASA Research Announcement (NRA).

Boundary Layer Physics: The viscous boundary layer near the surface of a hypersonic vehicle determines the aerothermodynamic environment seen by the material on the vehicle surface. Laminar-turbulent transition of the boundary layer has a profound impact on vehicle drag and surface heating, as well as the performance of scramjet inlets.

Primary research challenge involves accurate yet efficient prediction and control of transitional and turbulent boundary layers in the presence of shocks, high-temperature effects, non-smooth body surfaces with difficult to quantify roughness distributions, ablation, surface chemistry, and typically unknown free-stream disturbance environment. NASA, SNL and AFRL all have foundational research efforts in this area. Additionally, there is an Air Force MURI effort addressing the characterization, modeling and control of nonequilibrium turbulence.

Shock-Dominated Flows: This area addresses challenges associated with: (1) simulation of hypersonic flows over bodies and (2) design and simulation of fundamental shock interaction experiments to understand the influence of strong shock interactions on the aerothermodynamic environment (e.g. transition, turbulence, heating, unsteadiness,…) Generation of fundamental physics models dealing with transition, turbulence, thermochemical nonequilibrium, gas-surface interactions, etc. in shocked flow environments are handled by other thrust areas. Simulation of shocked flows and design of canonical experiments using best available physics models is the responsibility of the shock-dominated flows thrust area. Both NASA and AFRL have foundational research efforts in this area.

Nonequilibrium Flows: This area addresses scientific challenges associated with the fact that frequently in hypersonic flows the time scales for molecular collisions and reactions are comparable to the characteristic time scales of the flow field. As a result, the definition of temperature is ambiguous, and the influence of finite energy transfer rates both within molecules and through chemical reactions must be considered in the modeling and simulation of the flow. NASA and AFRL have foundational research efforts in this area.

High-Temperature Materials and Structures: Ultimately, the survival of a hypersonic system depends on the ability of the material from which it is constructed to handle the extreme thermal loads of the hypersonic environment. Research challenges associated with this area include the development of fundamental knowledge and methods to design and process high-temperature materials and structures. NASA, SNL and AFRL all have foundational research investments in this area.

Environment-Material Interactions: Characterization, modeling and the eventual control of the complex chemical and thermodynamic interactions that occur at the interface between the extreme hypersonic environment and the high-temperature material on the surface of a hypersonic system is critical for the development of optimized, efficient hypersonic systems. This multi-disciplinary area integrates contributions from the aerothermodynamics and high-temperature materials research areas and addresses issues such as surface catalytic effects and chemistry which impact heat transfer to the vehicle. NASA, SNL and AFRL have investments in this research area.

Summary

This report contains the FY2008 Roadmap for the Hypersonics Programs of the Department of Defense as directed by the John Warner National Defense Authorization Act for Fiscal Year 2007 Pub. L. No. 109-364. The roadmaps herein were developed by Joint Technology Office on Hypersonics under the Office of the Undersecretary of Defense for Science & Technology.

Appendix – Technology Readiness Level Definitions